"On the Capacity and Residual Charge of Dielectrics as affected by Temperature and Time." By J. HOPKINSON, F.R.S., and E. WILSON. Received December 15, 1896,—Read January 28, 1897.

(Abstract.)

The major portion of the experiments described in the paper have been made on window glass and ice. It is shown that for long times residual charge diminishes with rise of temperature in the case of glass, but for short times it increases both for glass and ice. The capacity of glass when measured for ordinary durations of time, such as 1/100th to 1/10th second, increases much with rise of temperature, but when measured for short periods, such as $1/10^6$ second, it does not sensibly increase. The difference is shown to be due to the residual charge, which comes out between 1/50,000th second and 1/100th second. The capacity of ice when measured for periods of 1/100th to 1/10th second increases both with rise of temperature, and with increase of time, its value is of the order of 80, but when measured for periods such as $1/10^6$ second, its value is less than 3. The difference again is due to residual charge coming out during short times. In the case of glass, conductivity has been observed at fairly high temperatures and after short times of electrification; it is found that the conductivity after 1/50,000th second electrification is much greater than after 1/10,000th, but for longer times is sensibly constant. Thus a continuity is shown between the conduction in dielectrics which exhibit residual charge and deviation from Maxwell's law and ordinary electrolytes.

"On the Electrical Resistivity of Electrolytic Bismuth at Low Temperatures, and in Magnetic Fields." By JAMES DEWAR, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution; and J. A. FLEMING, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London. Received January 4,—Read January 28, 1897.

In a previous communication to the Royal Society we have pointed out the behaviour of electrolytically prepared bismuth when cooled to very low temperatures, and at the same time subjected to transverse magnetisation.* During the last summer we have extended these

* See 'Proc. Roy. Soc.,' vol. 60, p. 72, 1896. "On the Electrical Resistivity of Bismuth at the Temperature of Liquid Air," by James Dewar and J. A. Fleming. See also 'Phil. Mag.,' September, 1895, Dewar and Fleming "On the Variation in the Electrical Resistance of Bismuth when cooled to the Temperature of Solid Air."

observations, and completed them, as far as possible, by making measurements of the electrical resistance of a wire of pure bismuth, placed transversely to the direction of the field of an electromagnet, and at the same time subjected to the low temperature obtained by the use of liquid air.

Sir David Salomons was so kind as to lend us for some time his large electromagnet, which, in addition to giving a powerful field, is provided with the means of easily altering the interpolar distance of the pole pieces, and also for changing from one form of pole piece to another.

The form of the pole piece most frequently used was that of a truncated cone. The magnet was always excited by a constant current obtained from a constant potential circuit. To save the considerable labour of determining again and again the strength of the interpolar field, this was determined once for all, corresponding to various interpolar distances and a given exciting current. The field was measured by suddenly removing from it a small exploring coil of wire of known area, the same being connected to a standardised ballistic galvanometer.

By this means a curve was constructed which showed at once the axial interpolar field at the central point in terms of the interpolar distances, the magnetising current being kept constant. This curve proved, as was to be expected, to be nearly a rectangular hyperbola.

This being done the bismuth wire to be examined was formed into a narrow loop of a single turn, about 3 or 4 cm. in length, and the ends soldered to leading-in wires of copper. The loop was placed in a small glass vacuum vessel, with the plane of the loop perpendicular to the direction of the axial magnetic field of the magnet. The loop was placed at equal distances from the two pole pieces, and in a nearly uniform field of known strength.

The vacuum vessel was then filled up with either liquid air, a solution of solid carbonic acid in ether, or else simply with paraffin oil. In a fourth case the vacuum vessel was closed, and liquid air having been placed in it, this liquid was caused to boil under a reduced pressure of 25 mm., thus giving a temperature falling as low as $-203°$ C. In another experiment the vacuum vessel was dispensed with, the bismuth wire was simply wrapped in cotton wool, placed between two pieces of thin mica between the pole pieces, and by pouring upon the wrapping a copious libation of liquid air, the temperature of the bismuth wire was reduced to $-185°$ C.

In all cases great care was taken to avoid thermo-electric complications, by providing that the soldered junctions by which the bismuth wire is connected to the copper leading-in wire were at exactly the same temperature, and to secure this the junctions were always kept well covered with the refrigerating solution.

The bismuth employed was electrolytic bismuth pressed into wire 0·5245 mm. in diameter, and its purity was confirmed by spectroscopic examination.

These arrangements being made, the observations consisted in measuring the electrical resistance of the bismuth at one temperature, but when the transverse magnetic field had values varying from zero to nearly 22,000 C.G.S. units.

In the following tables the results are collected. The electrical resistivity of the bismuth is stated for each temperature, and for the various transverse fields employed.

As the specimens of the bismuth wire used in the various experiments had different lengths, the actual figures of observation are not given, but they have been reduced so as to give the volume resistivity of the bismuth, corresponding to a certain temperature and magnetic field strength.

In the case of the experiment in liquid air boiling under a reduced pressure, on account of the size of the vacuum vessel necessary to contain the required initial volume of liquid air, the pole pieces of the magnets could not be brought very near together, and hence the field could not be raised to a very high value.

Hartman and Braun's Pure Electrolytic Bismuth.

Resistivity of Bismuth Transversely Magnetised at Ordinary Temperatures (+19° C.).

Strength of field (C.G.S. units).	Volume resistivity in C.G.S. units.
0	116,200
1,375	118,200
2,750	123,000
8,800	149,200
14,150	186,200
21,800	257,000

Resistivity of Bismuth Transversely Magnetised at −79° C.

Strength of field (C.G.S. units).	Volume resistivity in C.G.S. units.
0	78,300
650	83,300
2,300	103,500
3,350	114,800
4,100	134,000
5,500	158,000
7,900	201,000
14,200	284,000

Resistivity of Bismuth Transversely Magnetised at −185° C.

Strength of field (C.G.S. units).	Volume resistivity in C.G.S. units.
0	41,000
1,375	103,300
2,750	191,500
8,800	738,000
14,150	1,730,000
21,800	6,190,000

Hartman and Braun's Pure Electrolytic Bismuth.

Resistivity of Bismuth Transversely Magnetised at −203° C.

Strength of field (C.G.S. units).	Volume resistivity in C.G.S. units.
0	34,300
2,450	283,500

Electrical Resistivity of Bismuth in C.G.S. units, transversely magnetised in a Constant Magnetic Field, but at variable Temperatures.

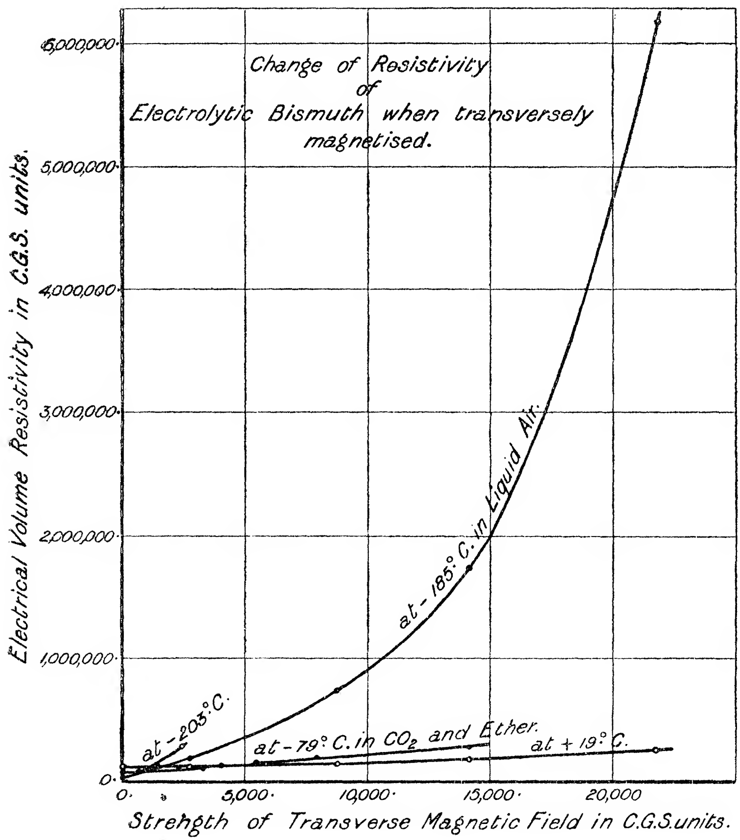
Temperature of the bismuth wire.	Out of the magnetic field.	In the magnetic field.		
		Strength 2450 C.G.S. units.	Strength 5500 C.G.S. units.	Strength 14,200 C.G.S. units.
+ 19° C.	116,200	123,500	132,000	187,000
− 79 „	78,300	105,000	158,000	284,000
−185 „	41,000	186,000	419,000	1,740,000
−203 „	34,300	283,500	—	—

It will be seen that the observations lead to the following conclusions. If the transverse field is zero, then cooling the bismuth always reduces its resistance. If then the bismuth is transversely magnetised, the resistance is increased, and for every temperature below the normal one (about 20° C.), there is some particular strength of transverse field, which just annuls the effect of the cooling, and brings the resistance of the bismuth back again to the same value it had when not cooled, and not in any magnetic field. Hence the curves showing the resistance at any temperature lower than the normal one (20° C.) as a function of the transverse field, cross the curve showing the resistance as a function of the field when taken at the normal temperature. These crossing points are, however, not identical for

different resistance-temperature-field curves. The lower the temperature the less is the strength of field which will bring the bismuth back to its original resistance when not cooled and not in the field.

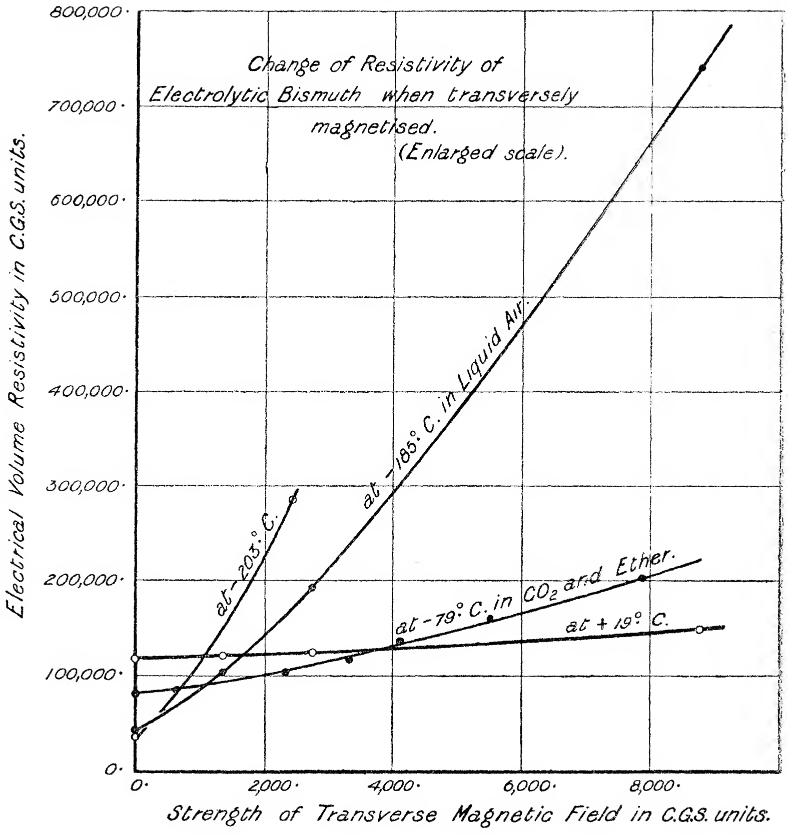
The observations have been set out graphically in the diagrams in figs. 1, 2, and 3, and it will be seen that there are in fig. 1 four curves. Each of these curves corresponds to a different temperature, viz., that of liquid air (—185° C.), liquefying carbonic acid in ether (—79° C.), ordinary temperatures (20° C.), and a fourth shorter curve, which corresponds to a very low temperature of —203° C., obtained by

Fig. 1.



evaporating liquid air under a reduced pressure. This last curve is only continued for a short distance. These curves show the mode of variation of the resistance of the bismuth at a constant temperature as a function of the transverse magnetic field; and they show how

FIG. 2.



remarkably the resistance is affected by such magnetisation. The curve of resistance taken in liquid air, shows that by a transverse magnetising field having a strength of 22,000 C.G.S. units, the resistance of the bismuth is made 150 times greater than the resistance of the same wire in a zero field, but at the same temperature.

The lower the temperature to which the bismuth is reduced the greater is the multiplying power of a given transverse field upon its electrical resistivity.

Hence a still lower temperature than we have been able to apply would doubtless render the bismuth still more sensitive to transverse magnetisation.

We have already shown that pure bismuth is no exception to the generally observed fact that all pure metals continuously lose their electrical resistivity as they approach in temperature the absolute

zero. Hence at this last temperature it should be converted into a non-conductor by a sufficiently strong transverse magnetisation. This result will have to be taken into consideration in framing any theory of electrical conduction.

In this respect bismuth is a remarkable exception to other metals. We have tried the effect of transverse magnetisation at low temperatures on zinc, iron, and nickel, but find no effect sensibly greater at low than at ordinary temperatures, although these metals have their resistance affected by magnetisation to a small degree.

Bismuth has an exceptional position amongst other metals, both in respect of its large coefficient of the Hall effect, and also in the degree to which its resistance is thus affected by transverse magnetisation, and in addition, as above shown, in the degree to which cooling to low temperatures affects this ability to be so changed by magnetisation.

Very small amounts of impurity in the metal reduce these remarkable qualities considerably.

We may mention here that we have repeated the experiments we made some time ago* on certain specimens of chemically prepared bismuth, and for which we found the electrical resistance had a minimum value for a certain temperature. We have again verified this fact, both for the same and for a similar specimen. In the former experiments the bismuth wire used was embedded in paraffin wax during the cooling, and the suspicion had arisen that strains might thus have been produced which had affected the results. In the repetition of the experiments, we suspended the bismuth wire freely in liquid air, so that no strains could be produced; and, in addition, we tried the effect of mechanical stress on the resistance directly. We satisfied ourselves that the cause of the anomaly in the behaviour of the chemically prepared bismuth in respect of electrical resistance at low temperatures was not to be found in any effect due to strain.

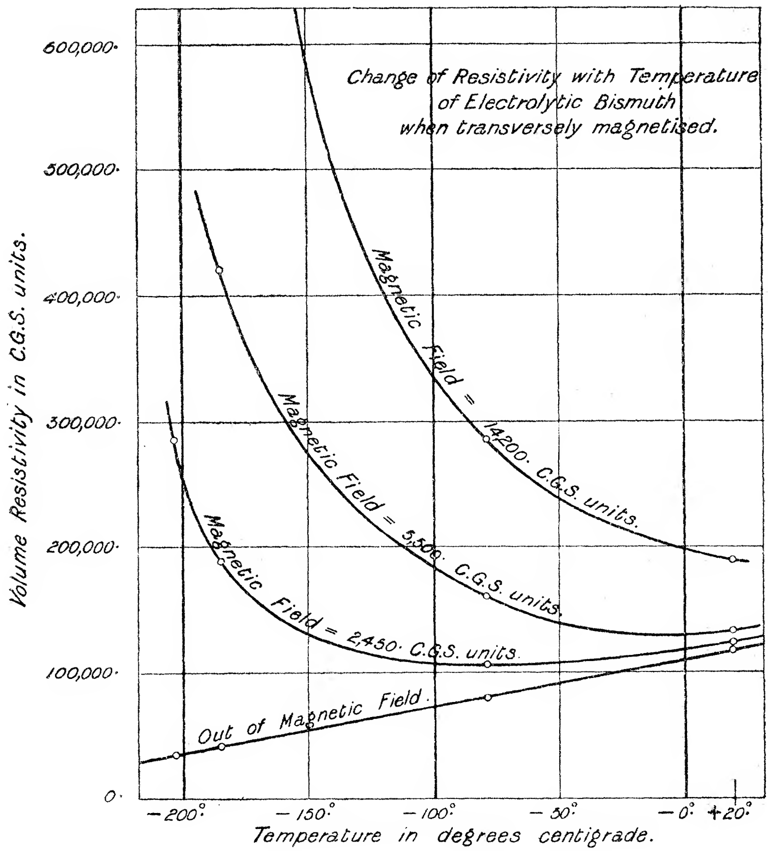
In fig. 3 a series of curves have been drawn showing the variation in resistivity of the electrolytic bismuth for certain constant transverse magnetic fields and varying temperatures. These curves were obtained by taking sections of the curves in figs. 1 and 2. The curves in fig. 3 are practically the continuation from 19° C. down to −186° C. of curves which have been given by Mr. J. B. Henderson,† for a range of temperature lying above 0° C.

They show that if a wire of electrolytic bismuth is placed transversely in a certain magnetic field, there is, for a wide range of field,

* See 'Phil. Mag.,' September, 1895, p. 303. Dewar and Fleming "On the Variation in the Electrical Resistance of Bismuth when cooled to the Temperature of Solid Air."

† See 'Phil. Mag.,' 1894, vol. 38, p. 488.

Fig. 3.



a certain temperature at which the bismuth has a minimum electrical resistivity, and, therefore, a zero temperature coefficient, and that the temperature of this turning point is higher the stronger the transverse field. These curves also show that at a temperature of about 150° C., the bismuth would probably cease to have its resistivity affected by a transverse magnetic field.*

In conclusion, we desire to mention the assistance we have received from Mr. J. E. Petavel in the work described above.

* Drude and Nernst ('Wied. Ann.,' vol. 42, p. 568) found that, with a transverse field of 7000 C.G.S. units, the total percentage increase of resistance of electrolytic bismuth was 22·0, 8·0, 1·0, and 0·4 per cent. respectively at temperatures of 16° C., 100° C., 223° C., and 290° C.